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Visual Knowledge in Tactical Planning:

Phase III Final Technical Report

ASQB-GM-91-030
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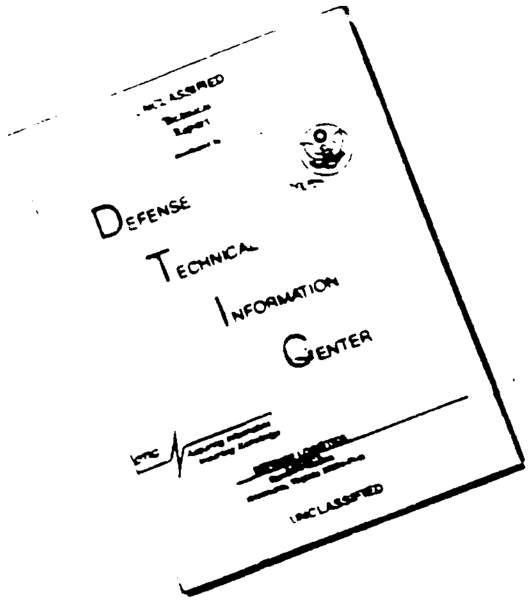

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This report summarizes the Visual Knowledge in Tactical Planning project. The report details the process and the results of Phase III which focused on prototype development. The purpose of the software prototype was to demonstrate the interaction between visual and symbolic reasoning processes exercised during the planning of ground tactical maneuvers. The first prototype was developed as a visuall oriented interface to a ground combat simulation. The tactical problem selected for implementation was that of selection of an avenue of approach based on trafficability and exposure. The prototype uses the symbolic representation of the typical Army plan interactively with the visual representation of the map annex to the plan. The prototype was developed on a Macintosh IIfx using the Supercard (tm) programming environment. Map images were scanned in and later manipulated use PhotoShop (tm) software.

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THIS REPORT HAS BEEN REVIEWED AND IS APPROVED

s/ James Gantt
Chief, MISD

s/ John R. Mitchell
Director
AIRMICS

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VISUAL KNOWLEGE IN TACTICAL PLANNING
FINAL REPORT

A. BACKGROUND

This document reports of the final, prototyping phase of the Visual Knowledge for Tactical Planning contract. Two previous phase reports have been produced and delivered under this project. In conjunction with this report, the three documents provide a complete record of the objectives, goals, approach, methodology, and results of the Visual Knowledge in Tactical Planning project. The purpose of the project was to develop a computer-based prototype that would demonstrate and facilitate the interaction between symbolic reasoning and visual reasoning the occurs when humans perform map-based tactical planning. This objective was successfully demonstrated to the customer on August 13, 1991 at the BDM facility in Arlington, Virginia, with positive comments provided at that time.

The first report, "*Visual Knowledge in Tactical Planning: Preliminary Knowledge Acquisition Phase 1 Technical Report," BDM/ROS-90-0563-TR, 5 April 1990* documented the initial structure of the program and the first six months of effort. Phase I focused on the acquisition of knowledge from domain experts in the field of ground combat tactical planning. Informal interview sessions were conducted using highly experienced combat veterans as domain experts. These knowledge acquisition sessions were recorded in video format for later reference. From these sessions, a knowledge document was prepared which captured in symbolic form the essence of expert understanding and inferencing of the knowledge which is represented on a map. The emphasis was on capturing that knowledge which the human tends to obtain, store and process in image form.

Phase II was focused on prototype software requirements and prototype design. The key to this phase was selecting a specific scenario which would be achievable within the constraints of the program and would clearly demonstrate the desired symbolic-visual interaction. One part of a tactical operations plan would be the avenue of approach, with a starting point, an objective point, and intervening obstacles. The avenue of approach was selected as the specific task for this project because it embodied all of the important

aspects of visual reasoning in planning. The symbolic knowledge that bore on the avenue of approach planning problem had been captured in Phase I. Specific sequences of user interactions in the planning process were defined and served as the functional requirements. A convenient prototyping environment was also selected, the SuperCard product which is Macintosh based. The card and stack metaphor provided a reasonable way to switch between symbolic displays and visual displays. The Macintosh also permitted the ready importation of processed imagery from other software packages. The results of Phase II were reported in the BDM technical report *"Visual Knowledge in Tactical Planning, Functional Design, and Knowledge Representation Phase 2 Technical Report," BDM/VSQ-91-0729-TR, 2 April 1991."*

This report continues that reporting process. It provides a complete description of the Phase III activities and describes the function and operation of the prototype. It should be emphasized that this was a first prototype only. Program constraints allowed only minimal involvement of the original experts to obtain their reaction to the prototype and to incorporate refinements. The prototype did demonstrate the symbolic - visual interaction and could be the basis for additional development, though likely in a more powerful environment. The details are provided below.

B. INTRODUCTION

The Visual Knowledge effort has been based on the human cognitive theories of Professor Lev Vekker, who worked as a consultant on this project, as described in the Phase I report. He has proposed that human knowledge is represented internally in three forms: symbolic, visual, and kinesthetic. Professor Vekker further has established that true intellect and complete understanding is represented by the ability to make isomorphic transformations between the three modalities of knowledge. This project pursued the application of the Vekker theories to the extent of an illustrative computer prototype demonstration. This project was initiated as an application of those theories to tactical planning. The project began with the premise that military tactical experts had exceptional visual knowledge gained from working with maps in various tactical planning situations; that the map itself conveyed substantial knowledge to the user and that the user performed certain operations which are essential visual in nature in using the map.

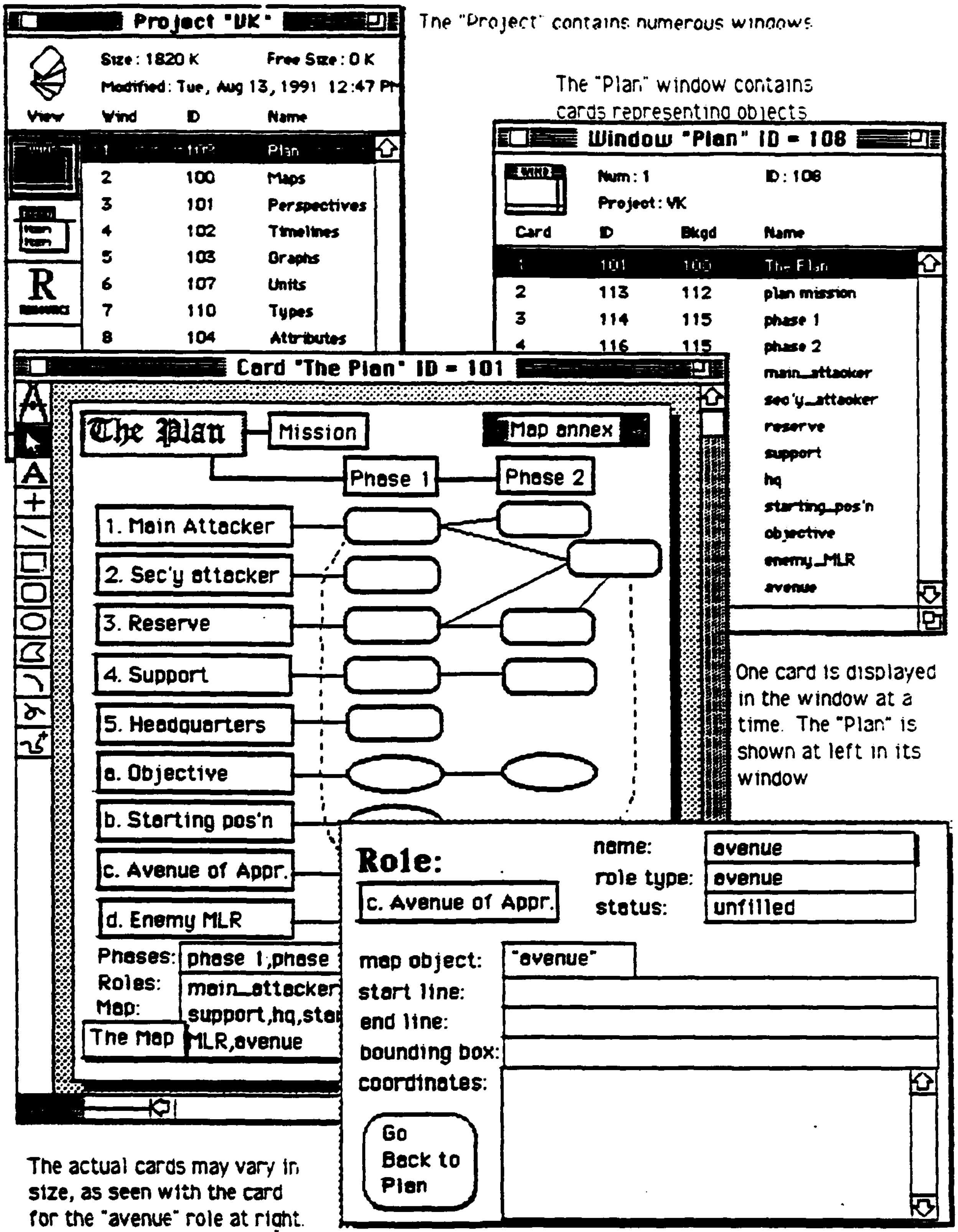
Further, the theory holds that the map user performs a variable combination of symbolic and visual reasoning operations in developing a tactical plan.

For example, an expert would be able to mentally construct perspective views and imagine how the scene would appear in reality based upon only the plan view. Additionally, by imagining the perspective view, certain other information would become relevant and important that was not obvious at first glance at the plan view. These essentially visual processes added understanding to the larger problem which was that of formulating a tactical plan.

The problem context given was support for the development of operation plans to be used by combat simulations. This application is useful in its own right, as simulation plan data development can be quite laborious. It also provides a fairly well specified description of the plan product. For purposes of this effort, the CORBAN simulation was used as the target for plan development since it includes an automated representation of Command and Control and accepts user supplied plans as its motivating form of input. CORBAN is a CORps BAttle aNalyzer combat simulation maintained by the Defense Nuclear Agency. CORBAN was originally developed by BDM.

Plans in CORBAN utilize Minsky's "frames" concept, as illustrated in Figure 1. The plan is an instantiation of a more abstract "Concept of Operation" in which the roles have been filled. For example, a concept of operation will have roles for "main attacker" or "reserve" or "avenue of approach". These must be filled by the assignment of subordinate units, in the first two cases, or by identification of a region of terrain, in the last instance. The problem used to focus the prototype was the selection of an avenue of approach.

The earlier phases included a survey of the knowledge base and collection of that knowledge. This phase built from a preliminary prototype initiated in Phase 2 with the selection of Supercard on the Macintosh as the prototyping tool. In the following sections the purpose of the prototype is described; then the nature of the prototype itself; followed by conclusions and recommendations.



...Plan Presented as a Frame

C PURPOSE

The prototype was intended to demonstrate the support of both symbolic and visual modes of interaction with the user in a typical tactical planning problem. It also was intended to show how automated and semi-automated reasoning, using the combination of visual and symbolic modes, would operate in the context of the tactical planning problem.

Symbolic reasoning includes rule based inference of the sort normally associated with expert systems, either goal driven (backwards chaining) or fact or situation driven (forward chaining). Visual reasoning includes numerous operations associated with image processing, such as blurring, edge detection, threshholding, and object recognition. Within the resources of this effort neither could be developed comprehensively. To do so would expend effort on implementing functionality already available in other , separate, but more fully developed software products. Rather, the focus in this effort has been on the interface between the visual and symbolic modes, and their integration into a combined tool. It is the ability to image a situation from symbolic to visual mode, operate on the situation in the visual mode, and then draw symbolic conclusions that has been the point of this experiment.

In keeping with the focus on the interface between visual and symbolic, the prototype was developed with the principle of supporting interactions but with functional operations within visual and symbolic modes stubbed out initially. Some of these functions were later inserted, though by no means all. For example, the prototype was never developed to include a fully functional symbolic reasoning engine of the sort typical of expert systems. Much of the structural support, such as instances and types, inheritance, and such was included. Thus, the sequencing of operations and control of the plan development process is manually driven by mouse clicks rather than by rule execution, as would be the case for fully automated reasoning. Development of a symbolic inference engine was seen as both beyond the resources available, duplicative of other efforts elsewhere, and (as it turned out) difficult given the choice of Supercard for the prototype. Similarly, the full repertoire of image processing algorithms would have included much that was computationally impractical for Supercard, and better developed in other software. For example, the program "Photoshop" by Adobe was used for blurring and threshholding the trafficability/vulnerability

data to form a diagram of barriers and corridors. These results were patched into the prototype, rather than duplicating the functionality of these tools within the prototype itself.

A full integration of such symbolic and visual algorithms would need to be accomplished in a more extensive prototype having a stronger software development support base than Supercard, which was originated mainly for audio/visual presentations. One such tool was identified, KBVision by AAI. However, its cost (approx. $26,000) and its extensive needs (workstation, LISP, etc.) necessary to support a prototyping effort along these lines put it outside the bounds of what could be considered in this project. Such software would be appropriate for the next stage in the development of these concepts where fully functional symbolic and visual components are integrated. Supercard, on the other hand, was quite useful for this prototype because its fundamental components, cards and the objects on them, are fundamentally visual as well as accessible symbolically. Thus, Supercard was, in this respect, well suited to an exploratory first prototype.

D. THE PROTOTYPE

The prototype used the Supercard metaphor of cards and stacks (windows) to implement the objects of the Visual Knowledge prototype. Objects such as military units, terrain regions or points of interest, and parts of the plan are instantiated as cards. Windows are used for different views of those objects. For example, one window contains the symbolically oriented plan objects such as roles, as illustrated in Figure 1. Another contains map oriented objects, and others support perspective views, timelines, and graphs. When an object can be perceived from more than one such view, a separate card is made for each of the corresponding windows. (A more general purpose software environment would allow "methods" to interpret the object differently, allowing objects to be represented by only one instance).

Objects to be presented are classified by type. A separate window is used for the type descriptors, or prototypes, for the objects. When a new object instance is created, the Type (prototype) information is copied from the card corresponding to the new object type in the "Type" window to become the background of the new card. Thus, the object (card) inherits some aspects of its type

implicitly by having a background that was derived from the "Type" card, while other aspects (generally functions) are exercised by explicit reference to the type card.

The object cards include graphics and fields. Fields are text objects that can generally be edited, and contain data about an attribute of the object. Each field is named. For the name of each field there can be found in a window "Attributes" a card giving attribute information. Some attributes are relationships, for which a card exists in a separate "Relations" window. The cards of the "Relations" window are prototypes for relationships that can be expressed as objects in any of the windows in which other object views are expressed. The type, attribute, and relation structures are illustrated in Figure 2.

When the prototype is actually run, the display appears as shown in Figure 3. The user is able to switch back and forth between different manners of viewing the subject by clicking in the corresponding window. A tools palette and the menus change to those appropriate to the mode and view being used. The relationship fields that appear on symbolic mode cards, such as the phases and roles of the plan, can be clicked on interactively to navigate among the cards of the symbolic objects. The tools palette can be used to create new objects. In the visual mode, these appear both as new symbols on the map and as individual cards. Figure 4 shows how such an object is converted to symbolic form as a new object in the "Plans" window by using the Mode change menu. Some objects, such as viewpoints, contain operational knowledge. In the case of a new viewpoint, which also exists as an object after it is drawn, clicking causes a transition to a different kind of scene: the perspective view. This is illustrated in Figure 5. Key points and other objects identified in one scene or mode, such as the perspective view, can later be expressed in the other modes.

The knowledge of how to transition an object among modes is contained in the type and its attributes in the form of scripts. In many cases the script is a general purpose one inherited from another attribute or the window. Figure 6, for example, gives the script for the attribute "box", a rectangular bounding box for an object or set of objects.

The visual mode allows symbolic knowledge to be expressed as images, and that data to be manipulated with image processing

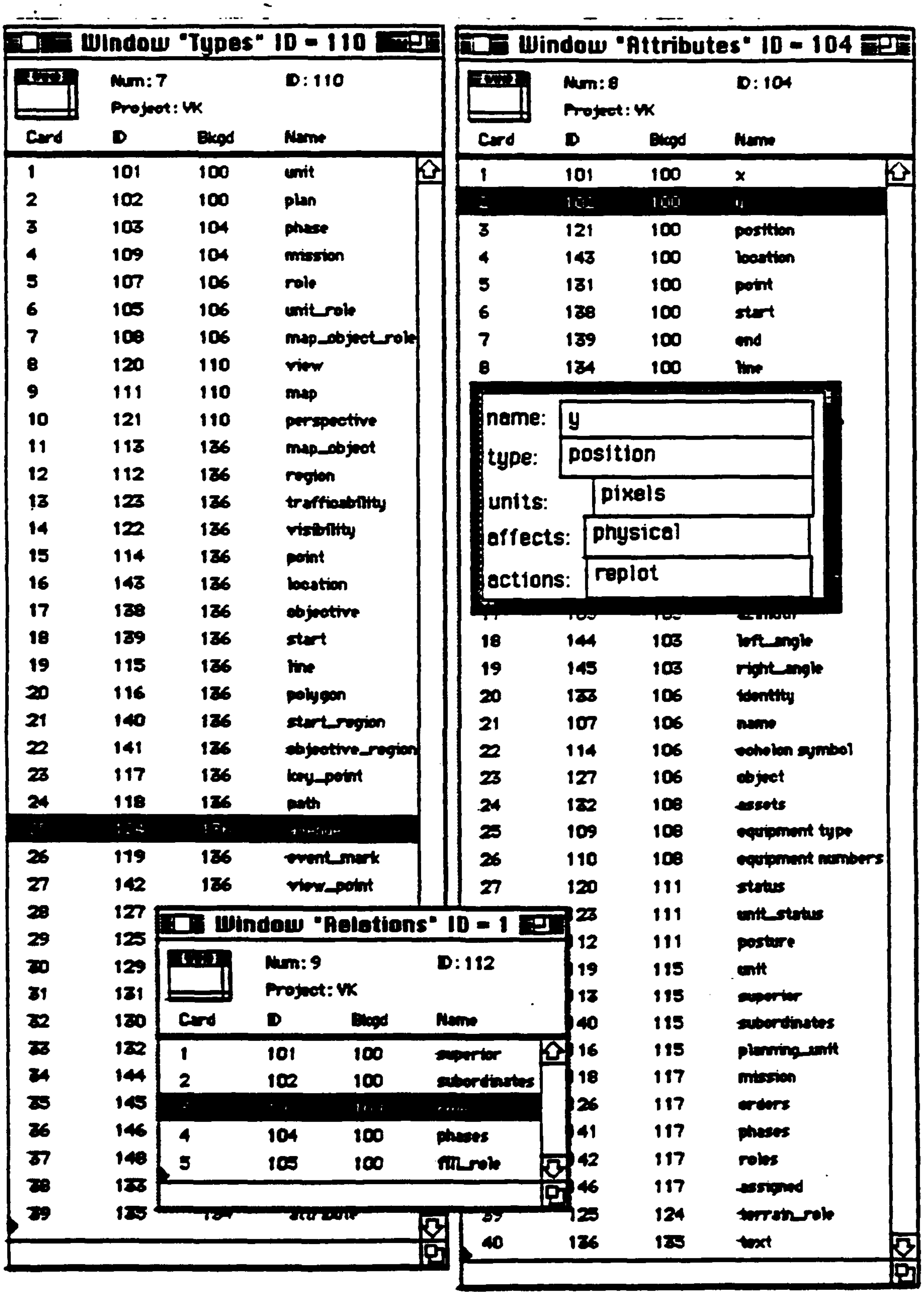


Figure 2. Type, Attribute, and Relation Structure

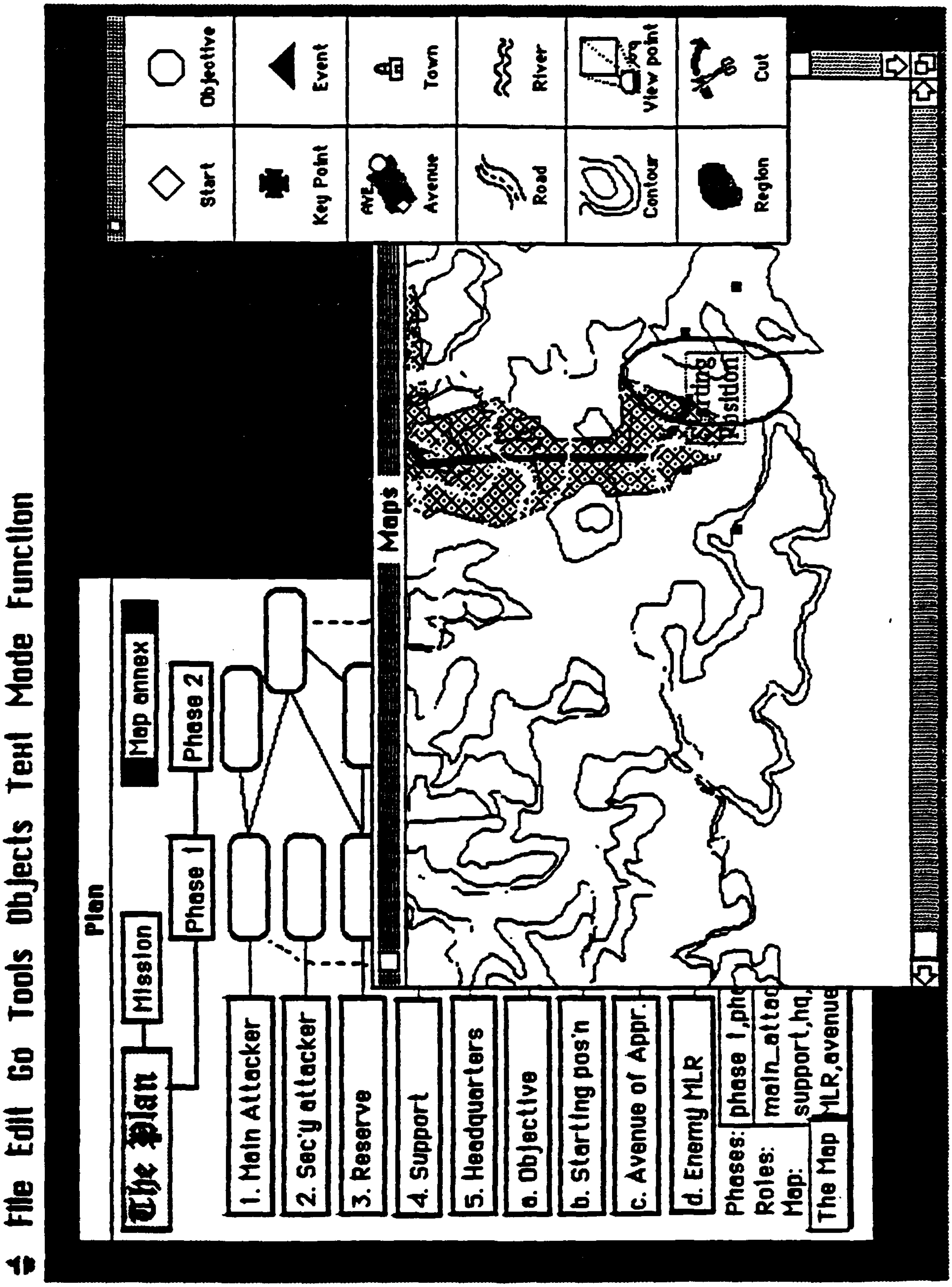
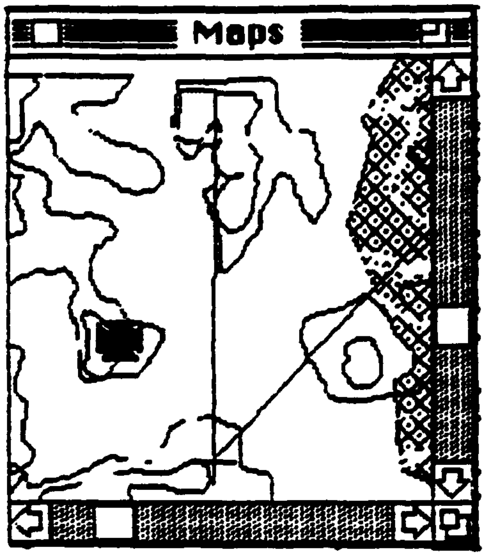


Figure 3. Prototype Display Mode



An object added to the map such as a key point added by the user using a tool is only a visual object. The "Mode" menu allows such objects to be selected and transformed into symbolic objects that appear in the Plan window as shown below. The system goes through all of the attributes, which contain the knowledge of how to express that attribute visually or symbolically.

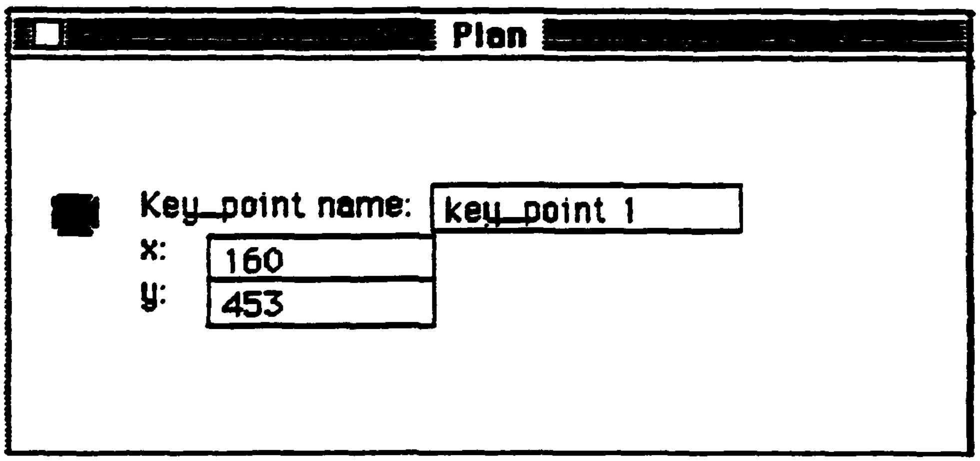
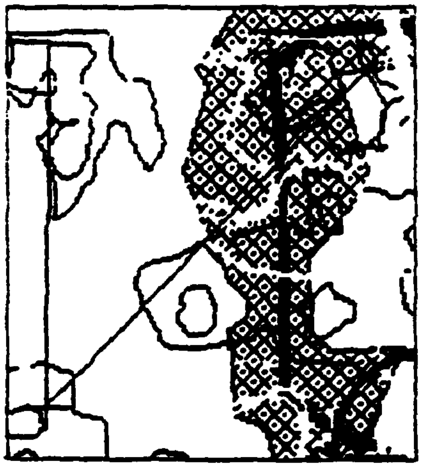
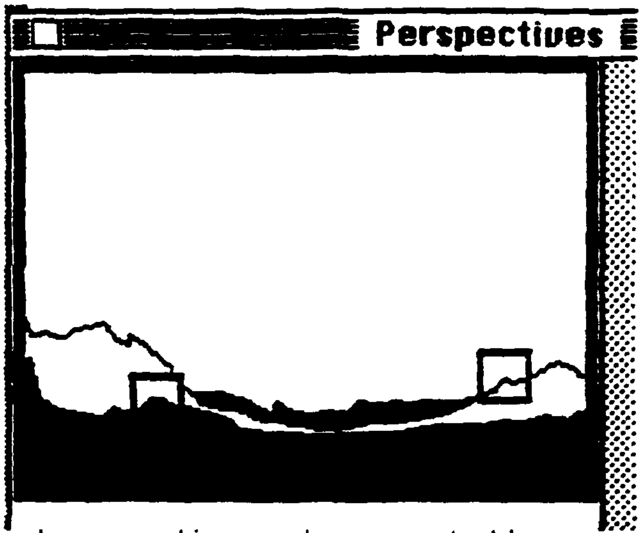


Figure 4. Visual and Symbolic Mode



A viewpoint is selected
on the map view



A perspective can be generated to
give a different kind of visual scene

Figure 5. Perspective Visual Mode

Card Script "box" ID = 129
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```
on get_value
  global vis_object -- long name of graphic object or card
  global valu_returned -- contents returned for each attribute
  global original_target -- attribute requested
  put the short name of this card into a_card
  if word 1 of name of vis_object is "card" then
    open vis_object
    if the number of graphics < 1 then
      pass get_value
    else
      put -32767 into v_top
      put -32767 into v_left
      put 32767 into v_right
      put 32767 into v_bottom
      repeat with n = 1 to the number of graphics
        put max(top of graphic n ,v_top) into v_top
        put max(left of graphic n ,v_left) into v_left
        put min(right of graphic n ,v_right) into v_right
        put min(bottom of graphic n ,v_bottom) into v_bottom
      end repeat
      put (v_left & "," && v_top & "," && v_right & "," && v_bottom) ¬
        into valu_returned
    end if
  else
    put rect of vis_object into valu_returned
  end if
end get_value

on vis_value
  global req_object -- long name of symbolic object card
  global vis_object -- long name of graphic object or card
  global original_target -- attribute requested
  global valu_returned -- value of parameter to be set
  put the short name of this card into a_card
  if (word 1 of name of vis_object is "card") then
    open vis_object
    if the number of graphics < 1 then
      pass get_value
    else
      put "false" into doit
      repeat with n = 1 to the number of graphics
        if the selected of graphic n is "true" then
          if doit is "true" then
            answer "vis_value of box won't work for >1"
            exit repeat
          end if
          then get the short name of graphic n
          put "true" into doit
        end if
      end repeat
      put the long name of graphic n of vis_object into g
    end if
  else
    put req_object into g
  end if
  if doit and valu_returned = "" then
    set rectangle of g to valu_returned
  end if
end vis_value
```

Figure 6. Typical Script

operations similar in effect to those that we unconsciously perform routinely as part of human vision. An example from the selection of an avenue of approach illustrates. Figure 7 shows a map scene view of knowledge about trafficability and vulnerability of a particular region of interest. The slow-go and no-go areas can be analytically derived from the terrain characteristics. DARPA has sponsored work on automated terrain analysis, some of which has been performed by George Mason University, Fairfax, Virginia. The process was not replicated in the prototype. The regions of vulnerability are those likely to be within line of sight to enemy occupied territory toward the NorthEast. In much of the region these are only ridgelines and forward slopes. In combining these considerations, the darkness is scaled to the undesirability of traversing these features.

The scale of resolution for the map features, however, is much finer than the scale of avenues needed for maneuver. A battalion or brigade typically needs space on the order of a kilometer or more. Small obstacles, unless found in clusters, are simply not important. There is a vision operation appropriate for making the necessary aggregation to an appropriate resolution: blurring. Figure 8 shows a 10 point gaussian blur of the previous Figure 7. (It is rendered as a dithered pattern for printing rather than the greyscale or false color image that would appear on the screen). The image can be thresholded at an appropriate level for the forces and operation to yield the image shown in Figure 9, which can then be reduced to a symbolic graphs of barriers and routes shown in Figure 10. When these are viewed superimposed on the original graphic depiction of the slow-go and no-go areas as in Figure 11, one can see which features were ultimately judged either significant or insignificant by this chain of visual reasoning.

Since the number of links and nodes in the graphs is relatively small, it is reasonable for symbolic logic to explore the options on an individual basis, much as a chess player explores individual moves. Likewise, the assumptions implicit in the visual process may be checked symbolically. For example, one route goes through an area that, on the original trafficability/vulnerability map, looks rather unsuitable. To support detection and reasoning about such features, another form of visual operation is needed: relations. In this case, a simple relation function could be invoked for a given route segment (or all segments) to detect which objects they intersect. (Such operations may even be supported by special purpose hardware).

Figure 7. Trafficability and Vulnerability

Figure 8. Ten Point Gaussian Blur

Figure 9. Blurred Image After Thresholding

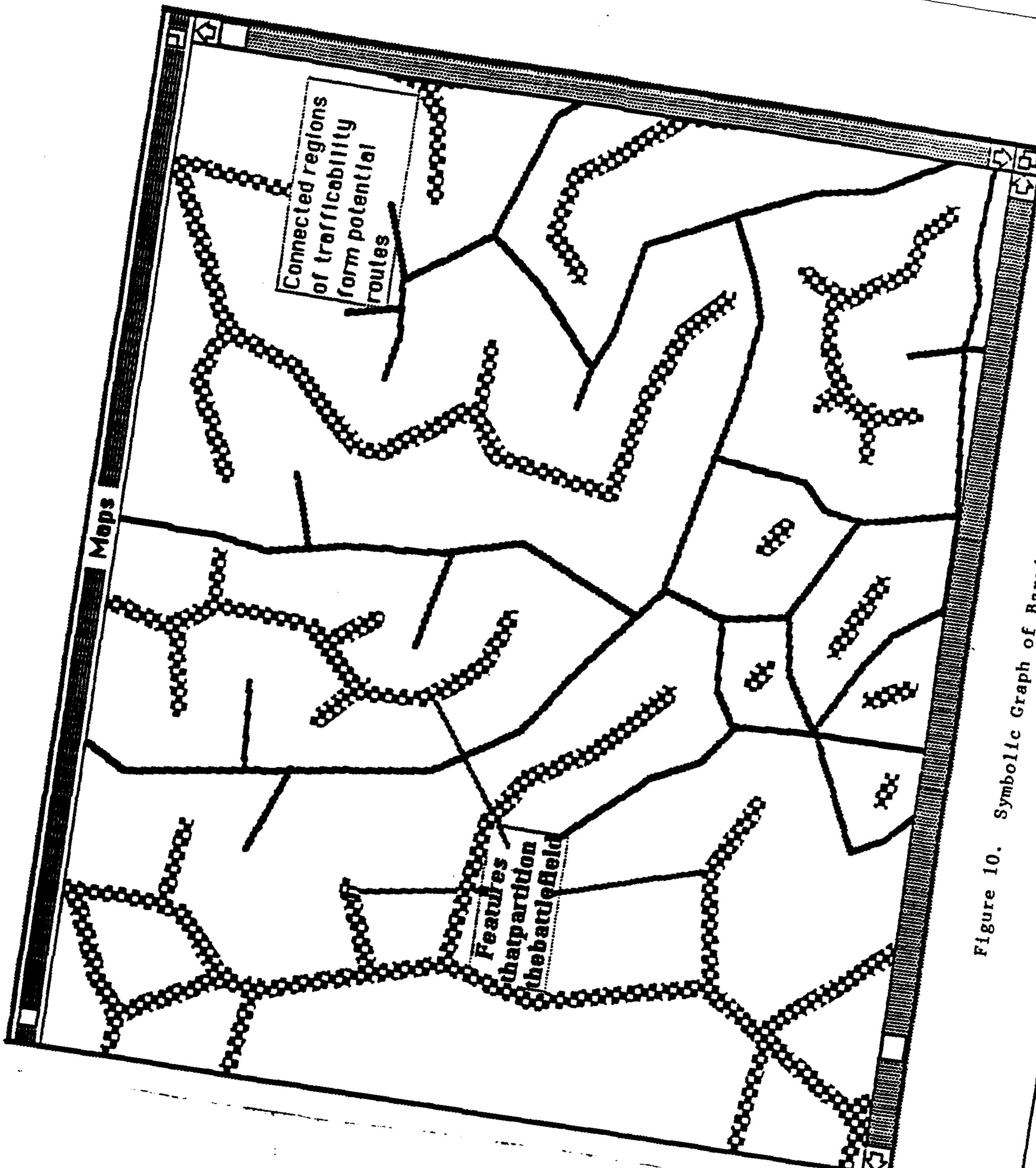

Figure 10. Symbolic Graph of Barriers and Routes

Figure 11. Barriers and Routes Superimposed on Slow-go and No-go Terrain

The relationships thus discovered can then be expressed as explicit objects in the symbolic mode, as shown in Figure 12.

Symbolic reasoning (not included in the prototype) would suggest candidate routes using conventional graph search techniques. These candidate avenues can be expressed visually as an object along the route filling the area bounded by the thresholded diagram. Based on the width of the avenue and other more detailed modeling, a movement profile that maps from space (distance along the route) to time can be created. This is expressed as yet another kind of view: a timeline. Local minima would be significant, resulting in the identification of event objects, which can then be transformed into graphic objects on the map and symbolic objects in the plan, and thus subject to further reasoning using conventional rule based approaches. Figure 13 shows the prototype graphics illustrating this process. These processes, however, were not functional within the prototype.

E. CONCLUSIONS AND RECOMMENDATIONS

In the course of this project, it became apparent that substantial work was going on at both extremes of symbolic and image processing but that there was little other work that explored the intersection of the two. Other work has dealt in great depth at replicating the inferential reasoning processes of experts, but that work has not fully developed the links to intuitive, object-oriented displays. This is the entire field of expert systems. At the other extreme, there has been substantial investment in starting from a bitmap image and, through various techniques, identifying the lines, regions, textures, and other visual properties of an image in order to form objects to which you can attach meaning and about which you can reason. This is the field of image understanding. The new ground which this project has broken has been to develop a cognitively valid and expert-guided, transparent interaction process between the otherwise relatively well understood processes of symbolic reasoning and image understanding, and to develop this interaction process in the context of a military need, tactical maneuver planning.

The prototype was able to incorporate all of the essential functions and processes that were identified as representative of the visual reasoning process. In this regard, it showed that more

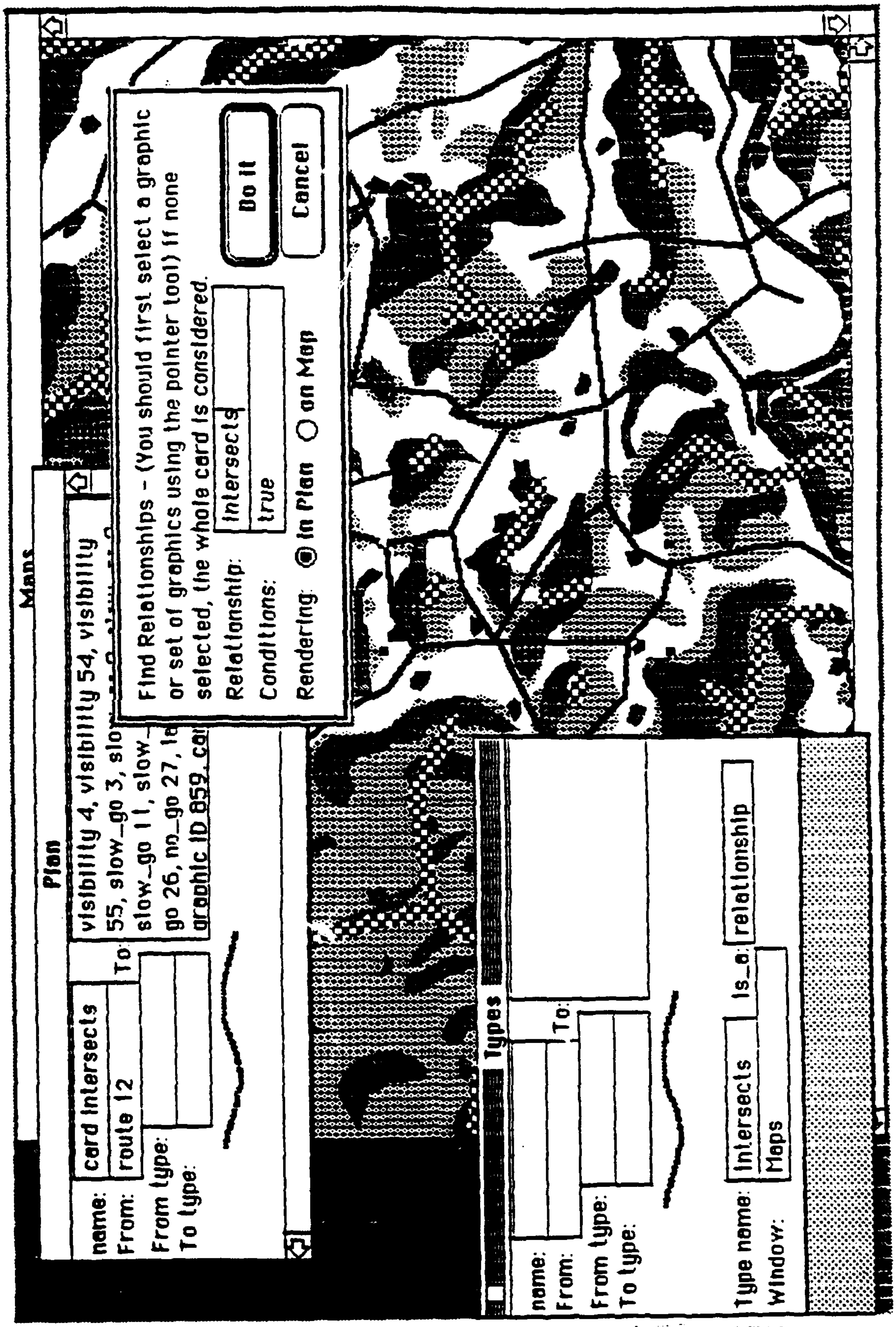

Figure 12. Relationships Expressed as Objects

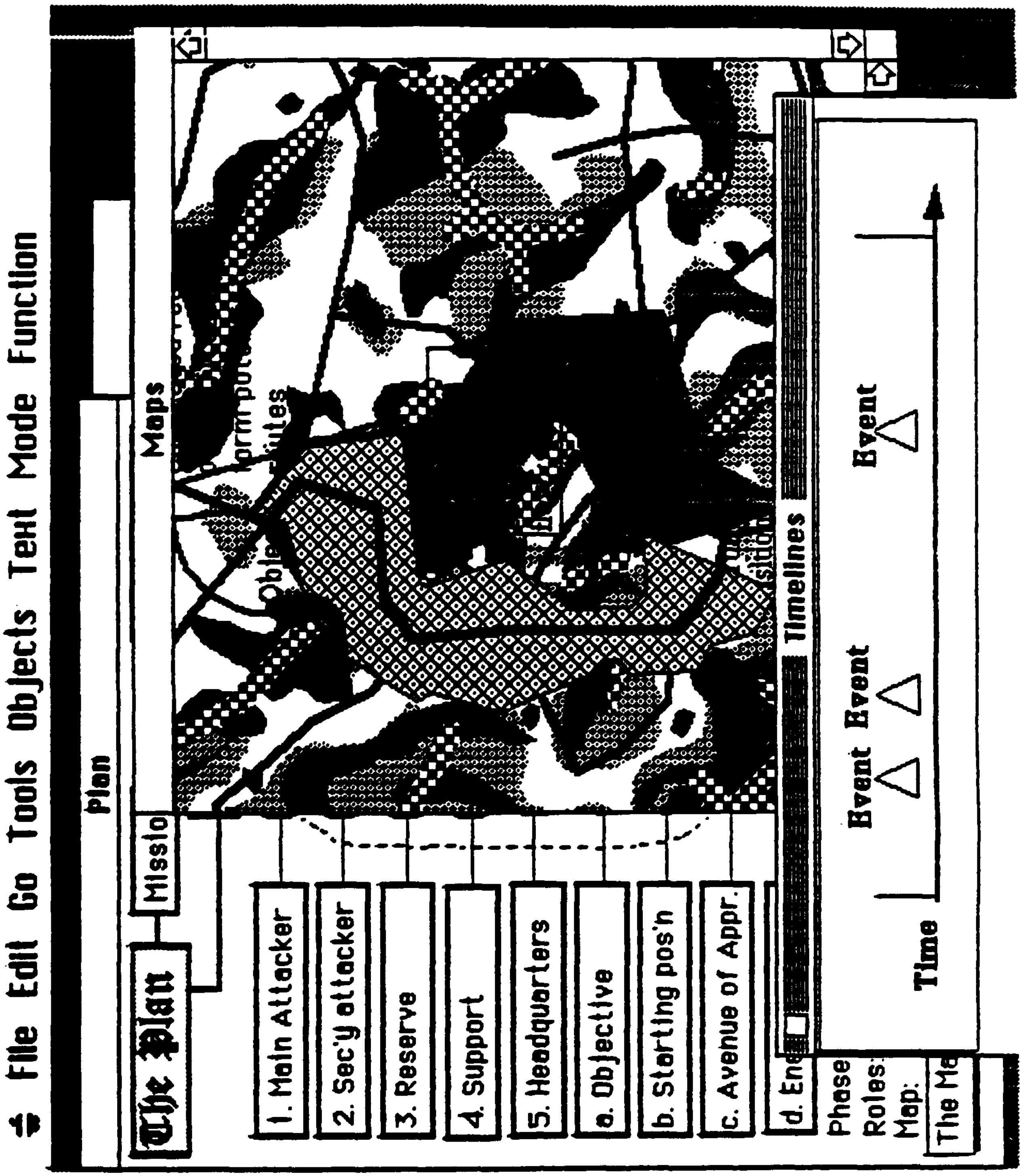

Figure 13. Prototype Graphic of Route Analysis

complex (and more representative of the human) reasoning processes are *possible to implemented* on current generation computer systems at a reasonably affordable level. Because no subject testing was involved, these is no firm conclusion of the power or effectiveness that such a planning tool might have. With the emphasis on aided tactical planning in programs such as the AirLand Battle Management (ALBM) program, the utility of a visually-based maneuver planning aid should be explored in a larger context.

The limitations that this project worked within were challenging. A robust inference engine to perform symbolic reasoning was not affordable and would have posed substantial integration problems. Likewise, bit-map processing of images (such as blurring and threshholding) were performed off-line and the processed images brought in when appropriate. Machine memory limitations precluded on-line image processing. As a result, the prototype and the scenario which is portrays appeared to be scripted. This is an accurate description, but it should be remembered that the purpose was to illuminate the interface between symbolic and visual reasoning processes and not to replicate or reinvent processes for which commercial software already provides efficient solutions.

In this regard, a next prototype would probably make use of a commercial AI shell (such as ProKappa by Intellicorp) for the user interface and the symbolic reasoning processes. A commercial image understanding tool (such as KBVision by AAI) would be useful to perform the visual reasoning processes. An underlying relational database would also be necessary at some early point to properly account for all of the objects in this highly object oriented environment. These tools were not available until very late in time frame of this project. Had they been available, their relatively high cost and the associated learning time for their efficient use may also have precluded their use. Clearly, the Supercard environment was adequate to the purposes of the initial prototype, but further work would best be performed with the more recent workstation-based tools which are now becoming available. In this regard, computational power has not been identified as a limit to a reasonable next step in this field.

This project has explored only a small part of what can be described as visual reasoning. The implications of understanding and representing in efficient form how the combination of symbolic and

visual reasoning might improve human performance in a variety of situations is immense. The psychology of learning and the design of training systems is an obvious candidate. Effective communication between teacher and student is highly dependent upon both parties making isomorphic transformations between symbolic and visual representations and processes. This extends to the tactile/ kinesthetic mode of knowledge representation where physical tasks are involved. The authors assert that understanding and reinforcing the interplay between the three basic forms of knowledge representation is essential to most human learning and decision making processes. The investigators in this project and the authors of this report hope that this project will give impetus to future research that will more completely define the processes and their application to militarily significant problems.